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STATUS AND PERSPECTIVES OF THE R&D PROGRAMS FOR THE XADS LINEAR ACCELERATOR

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In the last years, several laboratories in Europe have developed programs to study, design and test the main components of a high intensity proton accelerator. The broad field of applications covered by this new generation of accelerators (spallation sources, transmutation, radioactive beams, neutrino beams, ...) has contributed to a good synergy by developing complementary activities. These programs have succeeded in this preliminary stage to propose accelerator designs, which fulfil the required specifications, and to launch R&D programs necessary to prove the technical feasibility of the most critical components. For the XADS, the accelerator must exhibit an extremely low number of beam trips, and the new R&D programs must be focused on reliability and fault tolerance design.

In order to prepare the next R&D phase, in particular the proposals for the 6th FWP, the XADS (WP3) collaboration members have elaborated a technical proposal. It concerns experimental studies of long term operation and reliability of the injector, the development of cavities for the intermediate energy section and the construction of a complete high energy cryomodule which will constitute an ideal tool to study and develop all the reliability, fault tolerance and control aspects of this essential part of the accelerator.

In this paper, an overview of the main design studies, experimental results and foreseen developments will be presented. It covers the essential parts of the accelerator: ion source, RFQ, intermediate energy cavities and high energy cavities. Several prototypes were constructed and successfully tested, others are presently in the construction phase. New ideas are emerging in order to optimise some of these components, searching for an increase of performances or a higher reliability.

1. Introduction

The Preliminary Design Studies of an Experimental Accelerator Driven System (PDS-XADS) were launched mid 2001 in the frame of a large european collaboration supported by the EU (Euratom Integrated Project on Advanced Options for Partitioning and Transmutation of the 5th Framework Program). Five

[†] for the PDS-XADS Working Package 3 Collaboration: Belgium (IBA), France (CEA, CNRS, Framatome ANP), Germany (U. of Frankfurt, FZ Juelich, Framatome ANP GmbH), Italy (INFN, ENEA, Ansaldo), Portugal (ITN)

Work Packages (WP) cover the main issues of this project, the WP3 is dedicated to the design of a high intensity proton driver accelerator for an XADS. The accelerator characteristics (beam power, beam stability, availability and high reliability) determine the overall performance of the sub-critical system.

High intensity proton accelerators are presently considered for different projects in the world, in the U.S. the Spallation Neutron Source (SNS) [1] is under construction, in Europe and Japan other projects want to apply this kind of accelerator for different applications: nuclear physics [2], neutrino factories [3], multi purpose facilities [4], etc. For several projects (i.e. SNS) the beam operation mode is pulsed, while the ADS, as the nuclear physics projects, require a continuous wave (CW) beam. Nevertheless, most of the needed components are very similar conducting to a good synergy and collaborating perspectives.

At the present time (~ 50% of the PDS-XADS work) the WP3 has adopted a reference accelerator design: linear superconducting accelerator with a warm technology injector [5]. In the short term one of the main tasks will consist to establish a R&D program needed to be accomplished in the 6th FP in order to eventually launch the construction of a demonstrator for the 7th FP. Together with detailed specifications for the accelerator design, and cost assessment, the main goal of the WP3 group is to study all the relevant issues for high reliability which is the more peculiar aspect of this accelerator. A very low number of beam trips, as compared to different applications of similar proton accelerators, is considered as the most challenging aspect of the design and would induce a strong R&D program for the next years.

2. Driver Accelerator Reference Design

The initial specifications for the XADS have been evaluated and defined by the WP1 group [6]. The main required parameters for the proton beam that the accelerator has to provide are the following:

- Proton energy: 600 MeV.
- Max. beam intensity: 6 mA (*10 mA for the demonstration of concept*).
- Beam time structure: Continuous Wave (CW), including short beam “holes” (of a few tens of μ s) for on-line sub-criticality measurements.
- Beam power stability: $\pm 2\%$.
- Beam trip (longer than 1sec) number: less than 5 per year.

The WP3 group evaluated the main technical answers for an accelerator and its associated beam line able to ensure these characteristics. A superconducting linear accelerator and a doubly achromatic beam line penetrating the reactor vertically from above have been assessed to be the most suitable concept. This generic solution is valid for both the gas-cooled and LBE-

cooled XADS, and it also corresponds to the specification of the smaller scale XADS (MYRRHa) using 350 MeV protons

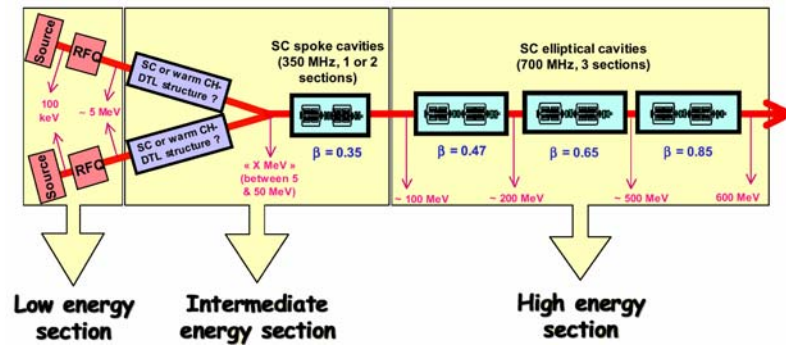


Fig. 1 Reference Design of a Proton Linear Accelerator for XADS

A superconducting linear accelerator has been preferred to a cyclotron because of its intrinsic advantages (large beam apertures, modular layout, efficiency), but especially because of its potentiality, once properly designed, in term of availability, reliability and power upgrading capability. As a matter of fact, a superconducting linac is composed with independently phased cavities, the high modularity of which allows a natural implementation of the required high reliability strategy: component de-rating, redundancy capabilities, and fault tolerance with respect to cavity failures.

According to these considerations, the WP3 group proposed a preliminary reference design for the XADS driver accelerator, which is shown on Figure 1. It is composed of a “classical” proton injector (ECR source + normal conducting RFQ structure + eventual additional structure that could be a superconducting CH-DTL or a normal conducting IH-DTL), followed by spoke and then elliptical superconducting cavities that bring the beam energy up to 600 MeV. The injector section, which does not exhibit any fault-tolerance capability, is duplicated for redundancy, with a fast switching magnet that can bring either beam (but not both) to the rest of the linac.

Several points linked with the high-reliability capability of the solution have to be demonstrated through R&D programs. The main objectives are the following:

- * Reach a sufficiently high reliability level for the injector section.
- * Reach RF performances for superconducting cavities well above the foreseen operating point (50 mT peak magnetic field, 25 MV/m peak electric field), and at nominal power (up to about 20 kW for spoke cavities, and 120 kW for elliptical cavities), to ensure the derating principle.

- * Prove the fault-tolerance capability of the solution by developing a fast RF control system able to manage cavity failures.

- * Check the compatibility of radioprotection and maintenance procedures with the foreseen operation schedule of the XADS (3 months operation / 1 month maintenance).

3. Present R&D activities and main results

During the last years, and related to the foreseen projects for high intensity proton accelerators, several R&D programs were started in different laboratories around the world. In the U.S. these activities were developed around the APT project at Los Alamos, and more recently within the SNS project. In Japan two laboratories KEK and JAERI joined its efforts to prepare a multipurpose facility. In this paper we will concentrate on the R&D launched in Europe by the partners of the XADS collaboration, or connected to other projects like EURISOL for the nuclear Physics, ESS, TRASCO, etc.

3.1 *Injector: Ion Source and RFQ structure*

Two major developments, with characteristics close to the XADS injector requirements, are presently in an active construction and test phase: IPHI in France and TRASCO in Italy. IPHI (Fig 1) is composed of a ion source, a RFQ copper structure and a beam analysis system. The source is now operational and reaches very high intensity proton beams (50 ...100 mA), the RFQ is under construction, and a complete beam test is planned for 2005-2006. This status of the TRASCO injector is very similar, the source is in operation and the first sections of the RFQ (Fig 2) have been constructed. Final tests with beam are planned in the 2004-2005 period.



Fig. 1 IPHI project, view of the Ion Source (CEA-CNRS)

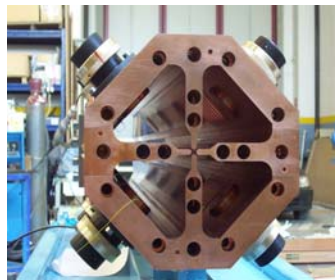


Fig. 2 RFQ structure TRASCO project (INFN – Legnaro)

Good performances of both RFQ are important milestones for the XADS project. Reliable operation of these complex copper structures relies on sophisticated technological and fabrication techniques. The excellent results obtained with the ion sources must be complemented by similar RFQ performances, in particular to demonstrate the feasibility of very high geometrical stability of these structures submitted to high RF power and thermal constraints.

3.2 Intermediate Energy Section

This is probably the less well known part of the accelerator. In old projects, and even in some more recent, a room temperature (RT) copper section was proposed for the 5 – 100 MeV energy range. Very often this choice was associated to the accelerator pulsed operation mode which allows to accept moderate structure losses. In the case of the CW beam required by the XADS project, the study of a solution using superconducting (SC) structures was considered from the very early stage of the study. The gain in installed RF power, and its associate economy on operating costs were major incentives for this choice.

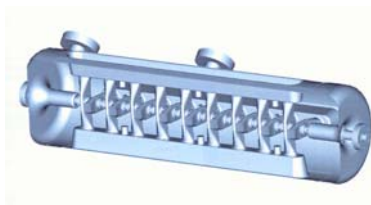


Fig. 3 C-H Superconducting structure (Univ. of Frankfurt)



Fig. 4 Copper interdigital structure (IBA- Belgium)



Fig. 5 Superconducting re-entrant structure (INFN-Legnaro)

As described in precedent paragraph, the reference design proposes to study an intermediate section composed of SC (or RT copper) structures from 5 to X MeV (X value \sim 20 MeV, not decided yet) and SC structures from this value to 100 MeV. Some prototypes are now under construction and test: CH SC structure (Fig. 3) proposed by the Univ. of Frankfurt, RT copper interdigital structure (Fig. 4) proposed by IBA (Belgium), or SC re-entrant resonators proposed by INFN Legnaro in Italy. The two first proposals, which offer very efficient and compact structures, are now in the construction phase. The short resonators, proposed by INFN Legnaro, offer higher modularity and the initial prototype results confirm the foreseen performances ($E_{acc} > 7$ MV/m)

In the second part of the intermediate section, the XADS proposal is to use “spoke“ SC cavities. These two gaps structures offer modularity, good stability and most important high beam tube diameter reducing the activation risks at this energy range. After the initial developments and results obtained in two U.S. laboratories (Argonne and Los Alamos), a first prototype has been studied and tested by the CNRS-IPN Orsay laboratory, in close collaboration with the french industry (CERCA-Framatome), who takes in charge the cavity fabrication. A view of the cavity, with the results at low temperature are presented in Fig. 6

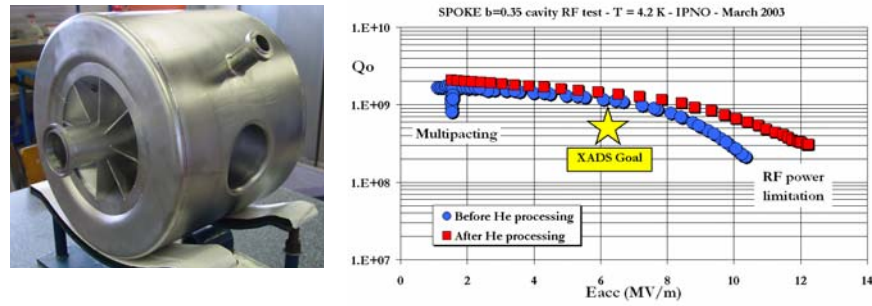


Fig. 6 Spoke Cavity Tests Results at 4K (CNRS-IN2P3)

3.3 High Energy Section

For this accelerating section, starting at 100 MeV, a general agreement of all laboratories involved in this field around the world, confirm the choice of multi-cell elliptical SC cavities. The excellent results obtained by the TESLA (electron-positron collider) project, and the confirmation by the european industry, of the technological feasibility of niobium cavities, has been recently confirmed by the succesful test of the first series of cavities for the SNS project in construction in the U.S.

In the XADS project, the cavities frequency and cell geometry have been adapted to the special requirements of the project. A preliminary R&D program was started in the frame of a collaboration between french (CNRS-CEA) and italian (INFN) laboratories. A first prototype (beta 0.65) was constructed and tested (Fig. 7) by the CEA-CNRS. During the last test, performed in a horizontal cryostat (CRYHOLAB facility) , the cavity was tested with its helium tank at 2K, in an environment close to the accelerator.

For the first modules of the accelerator high energy section, two prototypes (beta 0.47) have been constructed by the INFN and are ready to be tested at cryogenic temperatures (Fig. 8)

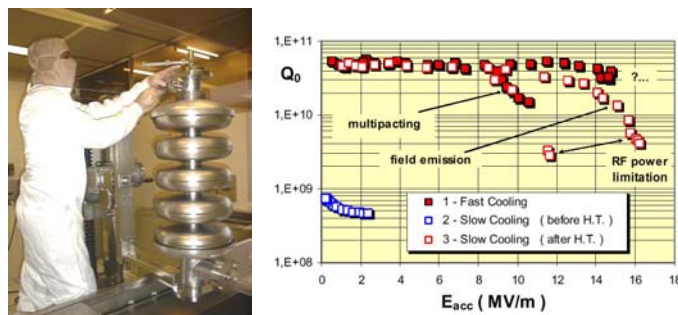


Fig. 7 Test of the beta 0.65 elliptical SC cavity (CEA-CNRS)



Fig. 8 700 MHz (beta 0.47) cavity (INFN-Milano)

To operate these cavities some important associated components are needed, in particular a RF power coupler (in the range of 100-150 KW) and a cold tuner for the fine adjustment of the resonant frequency of each cavity. Both developments are now in the preliminary design stage and will become major activities of this R&D program.

4. Proposals for a R&D program for XADS

In the last months the WP3 group, considering the present status of the R&D programs at different laboratories, and following the requirements of a XADS accelerator reference design has reached an initial agreement to propose a collaborative R&D program to be submitted in the next coming 6th FP call of proposals.

Table 1 summarizes the list of topics with the responsibilities accepted by the laboratory partners. The last line gives an estimation of the expected support from the 6th FP. Two main aspects may be emphasized in this preliminary proposal: a) reliability performances of the accelerator (injector, high energy

cryomodule and RF system) [7] , b) design of advanced prototypes for the intermediate energy section structures.

Low Energy	Intermediate Energy (Structures)				High Energy	RF System	Global Coherence
Injector Reliability	Spoke (SC)	C-H struct. (SC)	I-H struct. (NC)	Other Cav. (SC)	Cryomodule Reliability	Control System	<u>CNRS</u> CEA U. Frankfurt
<u>CEA</u> INFN CNRS U.Frankfurt	<u>CNRS</u> CEA, U. of Frankfurt, INFN FZ Juelich, IBA, Framatome				<u>INFN</u> CNRS CEA IBA	<u>CEA</u> INFN ITN IBA	INFN IBA ITN ENEA
Requested EU Contribution in the 6 th FP							
1M€	2 M€				2.5 M€	0.5 M€	0.5 M€

Table 1 Proposals for XADS accelerator R&D program for the 6th FP

The construction and test of a complete cryomodule for the high energy section (Fig 9) must become a high priority of this program. Besides the test at nominal power levels of cavities, couplers and cryogenic components, it offer the unique possibility to study and test at real scale the foreseen performances of a fault tolerant linear accelerator.

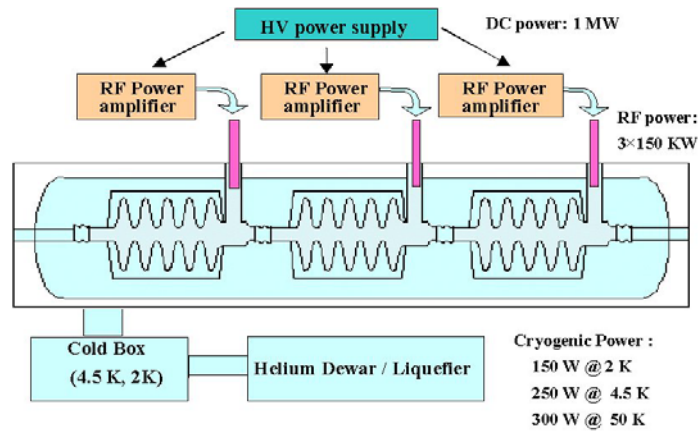


Fig. 9 High Energy Cryomodule: RF and cryogenic systems

Another important topic is the study and development of a RF system (Fig. 10) adapted to the fault tolerance operating mode. This system must handle beam trips, reacting with enough speed to retune the whole accelerator, in order to recover nominal beam conditions in a short time (less than 1 second). Digital techniques are necessary to meet the speed and software configuration requirements, it offers also a high level of integration with higher reliability. Original specialized control software and adapted interfaces to the RF power electronics systems, must also be developed and tested.

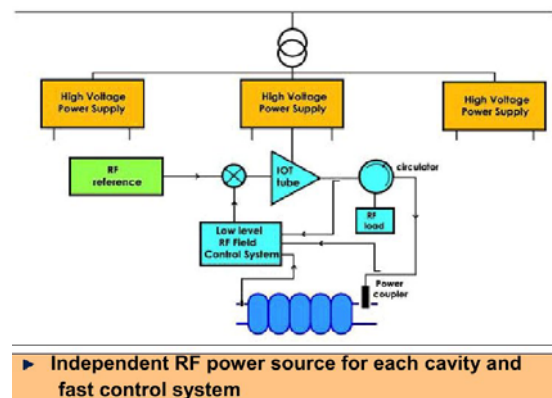


Fig. 10 RF system and associated low level control

Concerning the low and intermediate energy sections, two major topics are proposed: 1) reliability studies with the injector, performing long term uninterrupted beam runs of several months, 2) continuing the study and development of accelerating structures for the intermediate energy range in order to get more experience and results with new prototypes.

Acknowledgments

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